

The Design and Operation of Beam Auto Tracker for SRTM

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A beam auto tracker (BAT) was implemented for the Shuttle Radar Topography Mission (SRTM). It was designed to guard against excessive dynamic inboard/outboard beam misalignment, the occurrence of which would affect height accuracy. This paper addresses the concern of beam misalignment for a fixed baseline interferometric synthetic aperture radar (IFSAR) such as the one flown in SRTM, describes the causes of misalignment and the mitigation measures taken to reduce misalignment, followed by the BAT design considerations and its implementation and operation details.

For a fixed baseline IFSAR system in which two antennas are separated by a structure, electrical beam alignment between the two antennas is important. For SRTM, the inboard antenna, located in the shuttle cargo bay, provides the transmit beam and together with the outboard antenna, located 60m at the tip of the mast, receives the reflected echoes as an interferometer. This single-transmit-antenna dual-receive-antenna configuration requires the outboard and inboard beams be sufficiently aligned in order that adequate signal be received by the outboard antenna. Large and excessive misalignment would reduce signal-to-noise ratio (SNR) of the outboard channel signal, which in turn would degrade the height accuracy. The inboard/outboard beam alignment is required to be within 10% of the beam-width, as a design rule of thumb. For SRTM, given the inboard antenna azimuth beam-width of 0.25° , the misalignment cannot be greater than 0.03° in azimuth for these two antennas separated by 60m. Because the elevation beam-width is considerably larger (ranging from $5-14^\circ$), beam alignment in the elevation direction was not as big a concern.

The causes of inboard/outboard antenna misalignment can be classified as static, quasi-static and dynamic based on the frequency of misalignment disturbances. The static misalignment is a constant, which can be caused by, e.g. 0G unloading and other implementation errors. The quasi-static misalignment is slow varying, which can be caused by on-orbit thermal behavior. The dynamically induced misalignment is mainly caused by thruster firings of the shuttle in order to maintain required mapping attitude. Pre-mission analysis showed that the thruster firings could induce outboard antenna motion as large as 0.12° with a period of 8 seconds.

For SRTM, most of the static and quasi-static caused-misalignments were mitigated through design control and implementation, such as using a rigid and thermally inert structure and a shorter outboard antenna, and performing rigorous alignment and analysis. A two-axis adjustment mechanism was also implemented, located at the joint of the mast tip and the outboard antenna, to allow for manual adjustment of static or quasi-static misalignment on orbit. However, this manual

adjustment would not be effective in compensating for the thruster firings induced misalignment because its relatively high frequency of occurrence. The beam auto tracker (BAT) was considered as the only effective countermeasure for such dynamic misalignment.

The concept of the BAT is based on the same concept of a mono-pulse tracking radar. Instead of tracking a moving target as is the case for the tracking radar, the BAT was designed for the outboard receive antenna beam to track the inboard transmit antenna beam with sufficient rapidity and accuracy to bring them into alignment. This is possible because the outboard antenna is a phased array with beam steering capability in the azimuth direction.

The outboard phased array antenna was divided into two halves in the azimuth direction, a phase-delay was inserted between these two halved apertures, and both halves were re-combined, creating a composite beam steered away from the pointing direction of the full-aperture beam. The value of phase-delay determines the angular offset from the full-aperture beam and the sign of phase-delay determines the direction of the offset, in the fore or aft direction. When the BAT is activated during operations, the fore and aft beams are formed alternating in time, each beam dwelling over an integration period during which the received energy, as reflected from the target area illuminated by the inboard antenna beam, is integrated. The fore and aft energy estimate would be equal if the outboard beam is in perfect alignment with the inboard beam when the target area is homogeneous. The imbalance (difference) between fore and aft energy estimates would be indicative of beam misalignment and the outboard beam would be steered toward the direction where the energy estimate is lower, to zero out the difference when it is in alignment with the inboard transmit beam.

The target inhomogeneity and the speed with which the Shuttle travels through the target areas, i.e. from ocean to rugged coastal terrain to desert, can lead to target-dependent error even if the antennas are in perfect alignment, causing undesired steering compensation. The signal-to-noise ratio of echoes and the inherent system noise imbalance also affect the sensitivity and accuracy in steering the outboard beam. Since SRTM radar operates in ScanSAR mode with multiple beams scanned in the elevation direction, estimates need to be made for each beam. These considerations and the expected "worse" case dynamic motion were used to evaluate design trades, tracking algorithms, and operating parameters, through simulation and testing.

During the mission, the BAT was activated in the checkout phase of the mission and the above parameters were adjusted to optimize the tracking performance using a few selective data take opportunities. The tracking behavior was compared against other independent measurements such as metrology measurements of outboard antenna structure motion and Doppler centroid history as derived from the digitized radar signals. More BAT design parameters and operation details will be provided in this paper.

Through this BAT evaluation and other alignment adjustment steps during the checkout phase, it was determined that the overall beam alignment, after removing the static misalignment by manually adjusting the mechanism, was adequate without needing the BAT. Although the BAT seemed to improve alignment, leading to slightly better SNR of the outboard signal, the improvement would not affect height accuracy noticeably but would necessitate added complexity in post-mission data processing. The BAT was deactivated during most of the mission. However one can easily foresee that in a future mission where dynamic behavior of the system is not as good as SRTM or a twin spacecraft-radar system is required, beam alignment could be critical and a BAT or the like could be the only solution to maintain proper beam alignment.

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